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Original Article

Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men

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Abstract The effects of a 16-week training period (2 days per week) of resistance training alone (upper- and lower-body extremity exercises) (S), endurance training alone (cycling exercise) (E), or combined resistance (once weekly) and endurance (once weekly) training (SE) on muscle mass, maximal strength (1RM) and power of the leg and arm extensor muscles, maximal workload (W_{max}) and submaximal blood lactate accumulation by using an incremental cycling test were examined in middle-aged men [S, n=11, 43 (2) years; E, n=10, 42 (2) years; SE, n=10, 41 (3) years]. During the early phase of training (from week 0 to week 8), the increase 1RM leg strength was similar in both S (22%) and SE (24%) groups, while the increase at week 16 in S (45%) was larger (P<0.05) than that recorded in SE (37%). During the 16-week training period, the increases in power of the leg extensors at 30% and 45% of 1RM were similar in all groups tested. However, the increases in leg power at the loads of 60% and 70% of 1RM at week 16 in S and SE were larger (P<0.05) than those recorded in E, and the increase in power of the arm extensors was larger (P<0.05) in S than in SE (P<0.05) and E (n.s.). No significant differences were observed in the magnitude of the increases in W_{max} between E (14%), SE (12%) and E (10%) during the 16-week training period. During the last 8 weeks of training, the increases in W_{max} in E and SE were greater (P<0.05–0.01) than that observed in S (n.s.). No significant differences between the groups were observed in the training-induced changes in submaximal blood lactate accumulation. Significant decreases (P<0.05–0.01) in average heart rate were observed after 16 weeks of training in 150 W and 180 W in SE and E, whereas no changes were recorded in S. The data indicate that low-frequency combined training of the leg extensors in previously untrained middle-aged men results in a lower maximal leg strength development only after prolonged training, but does not necessarily affect the development of leg muscle power and cardiovascular fitness recorded in the cycling test when compared with either mode of training alone.

Keywords Strength training - Power - Endurance - Muscle hypertrophy

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Introduction

The use of multiple conditioning components to address both neuromuscular strength and cardiovascular health has become an important part of most recommended exercise regimens (Kraemer et al. *2002*). However, it has been shown previously that combined strength and endurance training, with a high volume and/or of a long duration, may lead to lower strength/muscle power gains (Hickson et al. *1980*, Häkkinen et al. *2003*, Kraemer et al. *1995*), as well as lower magnitude of endurance development (Kraemer et al. *1995*; Leveritt et al. *1999*), compared with pure training programs of resistance or endurance alone. These discrepancies between several research results have been reported to be based on the initial subject's physical fitness, the method of estimating endurance and strength performance, as well as with differences in frequency and volume of exercise used during these combined training studies (see Leveritt et al. *1999*). Thus, when the overall volume and/or frequency of training is low, but over a longer period (Häkkinen et al. *2003*), or high over a condensed training period of time (<12 weeks) with a higher frequency (and volume of training) (4–6 times per week) (Dudley and Djamil *1985*), a reduced improvement in muscle power output and/or muscular strength is observed. Previous studies on the effect of combined training on maximal oxygen uptake ($\dot{V}O_{2max}$) or maximal aerobic power have also produced conflicting results. The data available suggest that in previously non-endurance-trained men (Dudley and Djamil *1985*; Hickson et al. *1980*), or in previously resistance-trained subjects (Kraemer et al. *1995*), combined training does not affect the development of $\dot{V}O_{2max}$. However, these results disagree with studies showing a lower magnitude of endurance development with combined training in healthy active men and endurance-trained subjects (Kraemer et al. *1995*; Leveritt et al. *1999*).

To date, we are unaware of any research investigating the whole-body concurrent training-induced pattern of strength and power responses between the lower and, especially, the upper extremity muscles in previously untrained mid-life populations. In addition, few studies have been performed to provide a concurrent training-induced pattern to investigate whether the combined training had any effect with regard to maximal and submaximal endurance markers. Understanding the concomitant use of both programs in middle-aged men is an important aspect for this relatively unstudied age group.

This study examined the effects of a 16-week low-frequency combined once-weekly resistance and once-weekly endurance training on maximal strength and power of the lower- and upper-body extremities, workload, and blood lactate accumulation during maximal and submaximal cycling exercise, compared with pure twice-weekly strength and pure twice-weekly endurance training programs. It was hypothesized that low-frequency combined training in previously untrained middle-aged men would lead to similar gains in maximal strength and muscle power output of the lower-extremity muscles, as well as in various indices of maximal and submaximal cycling exercise, compared with pure strength and endurance programs. However, a different pattern of strength and power gains might be expected between the upper- and lower-extremity muscles, possibly due to the additive effect of cycling endurance training on leg strength and muscle power development.

Methods

Experimental design

To examine a long-term training scenario, 20 weeks of experimental period were used under carefully monitored conditions. The subjects were tested on four different occasions. Baseline testing was completed twice during the first 4 weeks of the study (at week 4 and at week 0), during which time no strength or endurance training was carried out. This was followed by a 16-week period of supervised experimental training with testing taking place at 8 and 16 weeks, using identical protocols. Experimental design and both training programs were similar to those reported previously (Izquierdo et al. *2004*).

Subjects

Thirty-one healthy men between the ages of 40 and 46 years volunteered to participate in a 20-week training study. Each subject gave written informed consent to participate in the investigation. The study was conducted according to the declaration of Helsinki. Before inclusion in the study, all candidates were thoroughly screened by a physician. The physical characteristics of the three subject groups are presented in Table 1.

Table 1 Physical characteristics of the strength (*S*), endurance (*E*) and combined strength and endurance (*SE*) training groups at pre-training, and after 8 and 16 weeks of training

	S (*n*=11)	**E (*n*=10)**	**SE (*n*=10)**
Age (years)	43.5 (2.88)	42.3 (2.64)	41.8 (3.69)
Height (m)	1.75 (0.03)	1.77 (0.05)	1.70 (0.07)

	S (n=11)	E (n=10)	SE (n=10)
Body mass (kg)			
Pre-training	86.2 (12.3)	86 (13.7)	80.1 (6.3)
8 weeks	85.7 (12.3)	85.8 (13.5)	79.4 (4.7)
16 weeks	85.9 (12.5)	85.6 (13.2)	78.9 (5.0)
Body fat (%)			
Pre-training	23.4 (4.2)	22.3 (6.2)	22.4 (4.9)
8 weeks	22.2 (4.6)	21.8 (5.6)	22.2 (2.9)
16 weeks	21.6 (4.9	22.2 (5.6)	21.4 (2.8)
Fat-free mass (kg)			
Pre-training	65.6 (5.9)	66.3 (7.4)	61.9 (3.9)
8 weeks	66.3 (6.8)	66.6 (6.6)	62.5 (3.7)
16 weeks	66.8 (6.1)	66 (6.2)	62.7 (4.2)

Group assignment

After baseline testing, the subjects were rank ordered by composite strength [one repetition maximum from a half-squat position], muscle power output, age, and peak power output during the incremental cycling test. Thereafter, the subjects were randomly assigned to one of the three training groups that performed two times per week heavy resistance training (S, n=11), endurance training (E, n=10), or combined resistance and endurance training (SE, n=10, once-weekly strength plus once-weekly endurance). To be considered compliant and remain in the study, subjects had to attend a minimum of 90% of the exercise sessions organized.

Measurements

A detailed description of the testing procedures has been given elsewhere (Izquierdo et al. 2004). In brief, bone-free muscle cross-sectional areas (CSA) of the quadriceps femoris (CSA_{QF}) muscle group and biceps brachii (CSA_{BB}) were measured with a compound ultrasonic scanner (Toshiba SSA-250) and a 5 MHz convex transducer. The percentage of fat in the body was estimated from the measurements of skinfold thickness. Lower- and upper-body maximal strength was assessed using one-repetition concentric maximum (1RM) actions in a half-squat ($1RM_{HS}$) and in a bench-press ($1RM_{BP}$) position, respectively. The power output of the leg and arm extensor muscles was measured concentrically in a half-squat and bench-press position using the relative load 60% of $1RM_{HS}$ and 45% of $1RM_{BP}$. Maximal aerobic power was measured by using a maximal multistage discontinuous incremental cycling test on a mechanically braked cycloergometer (Monark Ergomedic 818E, Sweden) (30 W increase every 3 min, at a pedaling frequency of 60 rpm). Following each workload, the test was interrupted for 60 s rest. Heart rate was recorded every 15 s during cycling (Sport Tester, Polar Electro, Finland), and averaged during the last 60 s of each workload. Before exercise and immediately after each exercise bout, capillary blood samples for the determination of lactate concentration were obtained from a hyperemic earlobe.

Training programs

The subjects in the S and E groups were asked to report to the training facility two times per week for 16 weeks, on nonconsecutive days, to perform dynamic resistance exercise or endurance training, respectively. The subjects in the SE group were asked to report to the training facility two times per week, for 16 weeks, on nonconsecutive days, to perform resistance exercise and endurance exercise, both once per week. The training programs utilized in the present study were similar to those reported previously (Izquierdo et al. *2004*).

Statistical analyses

Standard statistical methods were used for the calculation of the means and standard deviations (SD). Statistical comparison during the control period (from week –4 to week 0) was performed by Student's paired *t*-test. The training-related effects were assessed using a two-way analysis of variance (ANOVA) with repeated measures (group × time). When a significant *F* value was achieved, Sheffé's post-hoc procedures were performed to locate the pairwise differences between the means. Selected absolute changes were analyzed via one-way ANOVA. Statistical power calculations for this study ranged from 0.75 to 0.80. The $P \leq 0.05$ criterion was used for establishing statistical significance.

Results

Muscle CSA, body composition and maximal strength remained unaltered during the 4-week control period (from week –4 to week 0) in the S, SE ($P<0.05$ power at 45% of $1RM_{BP}$), and E groups.

No significant differences were observed in the magnitude of the increases in the muscle CSA_{QF} between S (14%, $P<0.01$), SE (12%, $P<0.01$), and E (10%, $P<0.05$). Muscle CSA_{BB} increased 9% during the 16-week training period in S, while no significant changes were observed in the E (1%) and SE (4%) groups.

During the early phase of training (from week 0 to week 8), the increase in $1RM_{HS}$ was similar in both S(22%) and SE (24%) groups, while increases in $1RM_{HS}$ at week 16 in S (45%) were larger ($P<0.05$) than those recorded in SE (37%). The differences between the groups were observed mainly during the last 8 weeks of the training (Fig. 1A). The increases observed in arm strength at weeks 8 and 16 in S (21% and 37%) were greater ($P<0.001$) than those recorded in SE (9% and 15%) and greater ($P<0.001$) than those recorded in E (0% and 0%) (Fig. 1B). During the 16-week training period, the increases in muscle power at the load of 60% of $1RM_{HS}$ at week 16 in S and SE were larger ($P<0.05$) than those recorded in E. This difference occurred mainly during the last 8 weeks of the training. No significant differences were observed in the magnitude of the increase in muscle power output between S and SE. The increases in power at the 45% of $1RM_{BP}$ at week 16 in S were larger ($P<0.05$) than those recorded in SE, while they remained unaltered in E. During the 16-week training period, no significant differences were observed in the magnitude of the increases in maximal workload (W_{max}) between E (14%, $P<0.001$), SE (12%, $P<0.001$), and E (10%, $P<0.001$) (Fig. 2A). The increase in the S group occurred mainly during the first 8 weeks of the training; during the last 8 weeks of training (between week 8 and 16) no further changes took place in the S group. During the last 8 weeks of training, the magnitude of the increases in W_{max} in E and SE was greater ($P<0.05$–0.01) than that observed in S (n.s.). No significant differences between the groups were observed in the training-induced changes in week 4 between E (15%, $P<0.05$), SE (15%, $P<0.05$), and S (17%, $P<0.01$) groups (Fig. 2B). Significant decreases ($P<0.05$–0.01) in average heart rate were observed after 16 weeks of training in 150 W and 180 W in the SE and E groups, whereas heart rate remained unaltered in the S group.

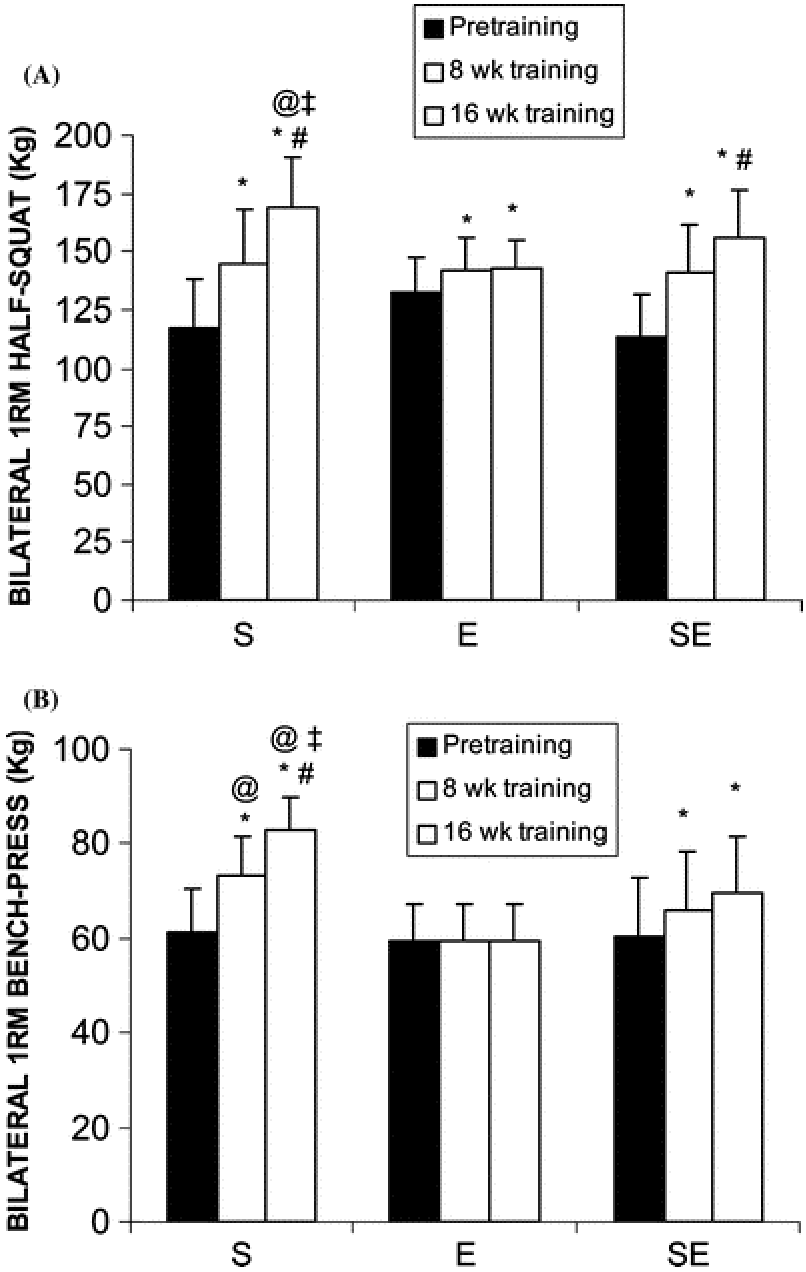

Fig. 1 Maximal bilateral concentric one-repetition maximum (1RM) half-squat (**A**) and maximal bilateral 1RM bench-press (**B**) at pre-training, and after 8 and 16 weeks of training. Values are means (SD). *Significantly different (P<0.05) from the corresponding pre-training value. #Significantly different (P<0.05) from week 8. @Significantly different (P<0.05) from the relative change at pre-training between the groups. ‡Significantly different (P<0.05) from the relative change at week 8 between the groups. Training groups: *S* strength, *E* endurance, *SE*, combined strength and endurance

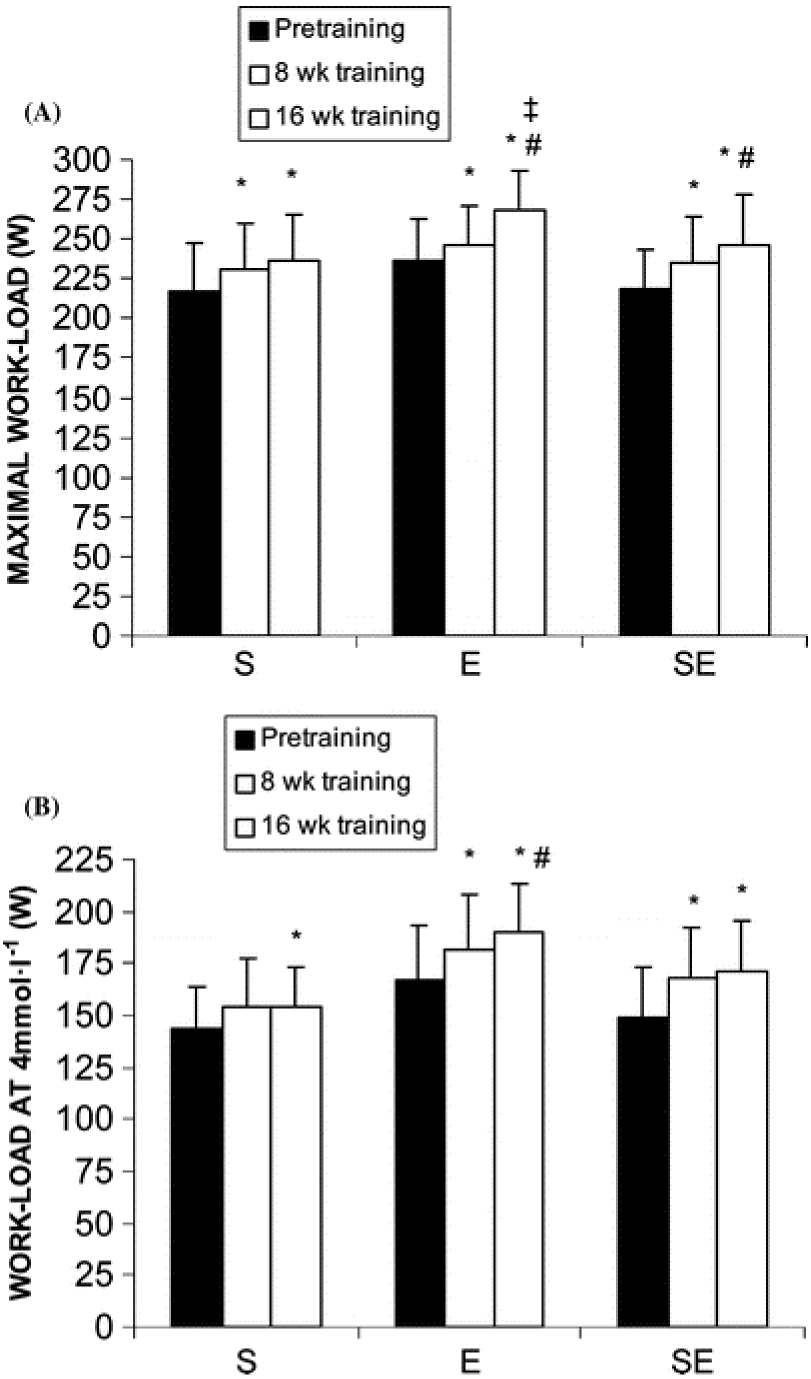

Fig. 2 Maximal workload (**A**) and workload associated with a blood lactate concentration of 4 mmol l^{-1} (**B**) attained during a maximal multistage discontinuous incremental cycling test at pre-training, and after 8 and 16 weeks of training. Values are means (SD). *Significantly different (P<0.05) from the corresponding pre-training value. #Significantly different (P<0.05) from week 8. ‡Significantly different (P<0.05) from the relative change at week 8 between the groups

Discussion

A unique approach in this study was the comparison between a combined once-weekly upper- and lower-body resistance training and once-weekly cycling-endurance training group with two groups which trained twice weekly for either resistance only or endurance only. The primary findings of this study were that prolonged low-frequency combined resistance and endurance training led to great gains in maximal dynamic strength, power-load characteristics of the leg and arm extensors muscles, as well as in cardiovascular fitness with only once weekly resistance exercise or once weekly cardiovascular exercise sessions.

During the initial 8 weeks of training, the combined endurance and heavy resistance training program led to great gains of the same magnitude (22% and 24%) in maximal dynamic strength characteristics of the leg extensors muscles in groups S and SE, respectively. Previous studies have also shown that concurrent resistance and endurance training can result in similar gains in maximal strength as those from resistance training alone (Bell et al. 1991; Häkkinen et al. 2003; McCarthy et al. 2002), and that it is possible to obtain substantial strength or cardiovascular gains from less weekly training frequency (i.e. once weekly or twice weekly for resistance or cardiovascular training, respectively) (Izquierdo et al. 2001, 2004) in previously untrained middle-aged and older men. However, during the last eight most-intensive training weeks of the 16-week training period, leg maximal strength increased at a greatly diminished absolute rate in the SE compared to the S group. Other studies, however, have shown that combined training can result in a diminished magnitude of strength development during both the initial and the whole period of training (Dudley and Djamil 1985; Hickson et al. 1980; Kraemer et al. 1995). The discrepancies of the results may be explained in part by the difference in the training frequency used during these studies. Thus, when the training frequency is high (4–6·times per week) (Dudley and Djamil 1985; Hickson et al. 1980; Kraemer et al. 1995), a reduced improvement in muscular strength has been observed with combination training as a result of the development of residual fatigue in the neuromuscular system (Hickson et al. 1980) due to high volume and frequency of both resistance and endurance training even during short-term training periods (<12 weeks) (Dudley and Djamil 1985; Hickson et al. 1980; Kraemer et al. 1995). A trend towards reduced strength adaptations with concurrent training was also observed with demanding overall training volume and/or frequency over a long period of time (Bell et al. 1991; Häkkinen et al.

2003). However, when the training frequency is low (2–3·times per week), there may be a synergistic effect of a combined strength and endurance training program in the increase observed in maximal strength during both short-term (<12 weeks) (Bell et al. 1991; McCarthy et al. 2002) and long-term training periods (>20 weeks) (Häkkinen et al. 2003).

The progressive combined heavy resistance and endurance training led to similar muscle leg CSA gains compared with the S group, with low training frequency (2 times per week) and the duration no more than 16 weeks. However, as previously reported, higher training frequency could also be related to larger muscle mass gains, at least in the pure strength training group (Häkkinen et al. 2003; Kraemer et al. 1995).

In addition to the gains in maximal strength, the present experimental concurrent training period also led to similar increases in leg power development at load of 60% of 1RM. These results are consistent with a previous study in older healthy adults (Izquierdo et al. 2004), which reported that combined once-weekly resistance and once-weekly cardiovascular training lead to similar gains in power of the legs as that for resistance training alone. However, these results disagree with studies showing a diminished enhancement with combined training of some indicators of explosive force development in nonspecific human muscle actions and isolated muscle groups such as: maximal rate of force development (Häkkinen et al. 2003), and angle-specific maximal isokinetic torque at fast velocities of contraction (Dudley and Djamil 1985). The different tests to estimate the explosive and mechanical power output in isokinetic/concentric and/or isometric type of actions in the lower or upper extremity could partly explain discrepancies between many research results (Leveritt et al. 1999, Häkkinen et al. 1998).

The use of the upper-body and lower-body power testing and training, along with the use of a total-body training program, is unique to the study and provides interesting data for the context of training components of health-related fitness. Due to specificity of training, 2 days·per week resistance training (S group) resulted in greater increases in maximal bench press than 1 day per·week being performed by the SE group. As expected, the present results demonstrated that the prolonged low-frequency resistance training alone (S group) led to greater gains in maximal arm extension strength and muscle power output than the SE group, mainly during the last 8 weeks of training, whereas no significant changes were observed in the E group.

Combined resistance and endurance training led to lower strength gains, but resulted in similar development of cardiovascular fitness when compared with either mode of training alone (Dudley and Djamil 1985, Hickson et al. 1980, Kraemer et al. 1995). In agreement with these findings, the progressive low-frequency once-weekly endurance training and once-weekly resistance training led to similar improvements in $\dot{V}O_{2max}$ (14%), and similar decreases of blood lactate concentration at absolute submaximal workloads during submaximal exercise (from 15% to 24%) as the corresponding relative changes observed in both E (from 15 to 26%) and S (from 7% to 15%) groups. This agrees with previous studies showing that in previously untrained older men, combining once-weekly endurance cycling exercise with once-weekly resistance exercise was as effective in eliciting improvements in endurance cycling fitness as twice-weekly endurance training alone (Izquierdo et al. 2004). However, during the last 8 weeks of training, the magnitude of the increases in W_{max} in E and SE were greater than that observed in the S group, which showed no further changes. This value is comparable with recent studies in previously endurance untrained men who have shown increases of 6–18% in $\dot{V}O_{2max}$ after 8–21 weeks of endurance training (Dudley and Djamil 1985, Hickson et al. 1980, Kraemer et al. 1995), but, as previously reported, slightly less than the value recorded for maximal strength of the lower extremities (Häkkinen et al. 2003). This similar increase in aerobic fitness in the combined group observed in the present study is even more interesting considering its low training-frequency (two training sessions per week), and the fact that this group performed one-half of the volume and weekly training frequency of resistance and endurance training compared with the S and E groups, respectively. Nevertheless, higher frequencies of training may result in different magnitudes of strength and endurance gains (Kraemer et al. 1995). As previously observed in previously untrained older men, it is also likely that in subjects performing a low-frequency training program, strength training may complement the adaptation to endurance training, and endurance training may complement the adaptation to strength training (Izquierdo et al. 2004). Because we were not able to measure the cardiovascular or neuromuscular training-induced stimulus of the resistance and cycling training sessions, the results of the present study should be interpreted with caution.

In summary, the present data indicate that low-frequency combined training of the leg extensors in previously untrained men can result in a lower maximal leg strength development after prolonged training, but that this does not necessarily affect the development of leg muscle power and cardiovascular fitness recorded in the cycling test when compared with either mode of training alone. However, for optimal muscle power development, especially of the arm extensor muscles, higher training volume may be required.

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